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A
DESCRIPTION
OF A
New PYROMETER,
WITH A
TABLE of EXPERIMENTS
Made therewith.

By J. SMEATON, F. R. S. *R*

AS it may tend to illustrate the following account, it may not be improper to make mention of the properties, that a complete instrument, for measuring the expansions, that metalline bodies are subject to by heat and cold, ought to be endowed with.

And, first, since the quantities of those expansions must be proportionable to the length of the bar

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to be measured; the longer the bar, the more sensible the expansion: And therefore such a construction is best, as (*cæteris paribus*) will admit of the longest bar.

Secondly, That the scale, whereupon those minute alterations are to be measured, ought to be, at least, so large, that the smallest change in the length of the bar, which the instrument is capable of being with certainty affected with, ought to be perceivable thereon.

Thirdly, As the same change, with respect to the position of the index and scale, will ensue, upon the supposition, that the materials, composing the instrument itself, are expanded in a certain degree, and the bar applied to be measured remains unchanged in its length; as if the instrument were supposed to suffer no expansion, and the bar to be measured were suppos'd to expand in the former degree: It is therefore necessary, that, in the making use of an instrument of this kind, the materials, of which those parts are composed, upon which the measure depends, and which may be called the basis thereof, should be subject to no expansion or contraction during such trial, or that the expansion or contraction thereof should be capable of being known, and accounted for.

Fourthly, That as all bodies grow still longer by the application of a greater degree of heat; to compare the expansions of different bodies, we ought to have some method of heating them in the same degree, notwithstanding their difference of texture, specific gravity, &c.

Fifthly,

Fifthly, The several parts, upon which the measurements depend, ought to be sufficiently large, to be themselves actually measured; that not only the proportions of increase of length in different metals, by the same degrees of heat, may be known; but also the quantities of those expansions, in real measures: Or, in other words, the proportions, that their increase of length, between certain degrees of heat, bears to the length of the bodies: By which means, we are enabled to ascertain the changes, that bodies undergo in their dimensions by the application of any given degrees of heat.

With respect to the first property, this instrument is capable of receiving a bar 2 feet 4 inches long, and might be made capable of receiving bars of a much greater length, of some kinds of materials, but not of others; on account of the flexibility brought upon them by a degree of heat not greater than boiling water.

The measures taken by this instrument are determined by the contact of a piece of metal with the point of a micrometer-screw. The observation is the best judg'd of by the hearing, rather than that of the sight or feeling. By this method I have found it very practicable, to repeat the same measurement several times, without differing from itself above one twenty-thousandth part of an inch. This principle of determining measures by contact is not wholly new; but has been employ'd on several occasions, as I am inform'd, by the late Mr. Graham: But the present manner of applying thereof, I believe, is so; and the degree of sensibility arising therefrom exceeds any

thing I have met with. As the method will easily appear by the draught (see *Plate XXI.*), I shall avoid a farther description of it in this place *.

As no substance has hitherto been discover'd in nature, that is perfectly free from expansion by heat, I chose to construct this instrument in such a manner, that the bar, which makes the basis of the instrument, shall in each experiment suffer the same degree of heat, as the bar to be measur'd: Of consequence, the measures taken by the micrometer are the differences of their expansion. The expansion then of the basis between two given degrees of heat being once found, the absolute expansion of any other body, by adding or subtracting the difference to or from the expansion of the basis, according as the body to be measur'd expands more or less than the basis, will also be determin'd.

When the instrument is made use of, it is immerg'd, together with the bar to be measur'd, in a cistern of water; which water, by means of lamps apply'd underneath, is made to receive any intended degree of heat, not greater than that of boiling, and thereby communicates the same degree of heat to the instrument, the bar, and to a mercurial thermometer immerg'd therein, for the purpose of ascertaining that

* I have lately seen an instrument at Mr. Short's, made by the late Mr. Graham, for measuring the minute alterations, in length, of metal bars; which were determin'd by advancing the point of a micrometer-screw, till it sensibly stopp'd against the end of the bar to be measur'd. This screw being small, and very lightly hung, was capable of agreement within the 3 or 4000th part of an inch.

that degree. That this may be truly the case, the water should be frequently stirr'd, that there may be no difference of heat in the different parts of the water: This being done, the height of the quick-silver appearing stationary, the contact with the screw of the micrometer also remaining the same, for a space of time, it is to be suppos'd, that the heat of the three bodies will be the same, as the heat of the water, however different they may be in specific gravity, &c. The whole difficulty is now reduc'd to this problem, viz.

To find the absolute expansion of the basis between any two given degrees of heat, not greater than that of boiling water.

For this purpose, let there be prepar'd a bar of strait-grain'd white deal, or cedar; which, it is well known, are much less expansible by heat than any metal hitherto discover'd: Let the bar be adapted to the instrument in like manner as the other bars intended to be measur'd; but that the softness of the wood may not hinder the justness of its bearings, let its ends be guarded with a bit of brass let into the wood at the points of contact, to prevent, as much as may be, the moisture or steam of the water from affecting the wood; let it first be well varnish'd, and then, being wrapp'd round with coarse flax from end to end; this will, in a great measure, imbibe the vapour, before it arrives at the wood. Let the cistern also be so contriv'd, that the instrument being supported at a proper height therein, the bar to be measur'd may, upon occasion, be above the cover, while the basis remains in the water: Thus will the cover
also

also be a defence against the moisture. Let the water in the cistern be now brought to its lower degree of heat (suppose at or near the freezing point), the basis having continu'd long enough in the water to receive the same degree of heat, and the wooden bar having been previously kept in an adjacent room, not subject to sudden alterations of temperature by fire, or other causes; let the bar be apply'd to the instrument, and the degrees of the micrometer and the thermometer read off, and set down; Let the wooden bar be then restor'd to its former place, till the water is heated to the greater degree intended (suppose at or near that of boiling water); the lid being now shut down, and the chinks stopp'd with coarse flax, to prevent the issuing of the steam as much as possible, let the wooden bar be again brought forth apply'd to the instrument, and the degrees of the micrometer and thermometer read off, as before: The difference of degrees of the micrometer, corresponding to the difference of degrees of the thermometer, will express the expansion of the basis between those degrees of heat; that is, upon the supposition that the wooden bar was of the same length, at the time of taking the second measure, as at the first: Indeed a measure can hardly be taken without any loss of time, as the whole of the instrument, when the hot measure is to be taken, is considerably hotter than the wooden bar; and, in case of boiling water, the steam being very repellent and active, the bar is liable to be sensibly affected in its length, before the measure can be taken, both by heat and moisture, which both tend to expand the bar: But as the quantity is small, and capable

pable of being nearly ascertain'd, a wooden bar, thus apply'd, will answer the same end as if it was unalterable by heat or moisture.

In order, therefore, to know the quantity of this alteration, let the time elaps'd between the first approach of the bar to the instrument, and the taking of the measure, be observ'd by a second-watch, or otherwise; after another equal interval of time, let a second measure be taken; and after a third interval, a third; and a fourth; the three differences of these four measures will be found nearly to tally with three terms of a geometrical progression, from which the preceding term may be known, and will be the correction; which, if apply'd to the measure first taken, reduces it to what it would have been if the wooden bar had not expanded during the taking thereof.

From a few observations of this kind, carefully repeated, the expansion of the basis may be settled; and this once done, the making experiments upon other bars will become very easy, and compendious.

The basis of this instrument (as well as other parts thereof) is brass. I chose this substance rather than any other whose expansion was greater or less, because I found, from some gross experiments previously made, that the expansion of brass was nearly a medium between those bodies, which differ most in their expansion: A considerable convenience arises from this circumstance; because as the measures, taken in common experiments, are their difference from brass, the dependence upon the thermometer will be less, as these differences are less. This precaution I have found the more necessary, as the greatest errors that experiments made with this instrument are subject to, seem

seem to be chiefly owing to the thermometer, tho' that which I us'd was well graduated, and good in other respects; but this must necessarily happen, as the scale and sensibility of the micrometer, when those metals were try'd which differ most from the basis, were greater than that of the thermometer.

The bar of brass which composes the basis is an inch broad by half an inch thick, and stands edgewise upwards; one end is continu'd of the same piece at right angles, to the height of three inches and an half, and makes a firm support for the end of the bar to be experimented; and the other end acts upon the middle of a lever of the second kind, whose fulcrum is in the basis; therefore the motion of the extremity of the lever is double the difference between the expansion of the bar, and the basis. This upper part of the lever rises above the lid of the cistern, so that it and the micrometer-screw are at all times clear of the water. The top of the lever is furnish'd with an appendage which I call the *feeler*; it is the extremity of this piece which comes in contact with the micrometer-screw. The construction and application hereof will better appear from the draught, than from many words. It hence appears, that, having the length of the lever from its fulcrum to the point of suspension of the feeler, the distance between the fulcrum and the point of contact with the bar, the inches and parts that correspond to a certain number of threads of the micrometer, and the number of divisions in the circumference of the index-plate; the fraction of an inch express'd by one division of the plate may be deduc'd: Those measures are as follows.

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	Inches.
From the fulcrum of the lever to the feeler	5.875
From the fulcrum to the plate of contact	2.895
Length of 70 threads of the screw . . .	2.455
Divisions in the circumference of the index-plate	100.

Hence the value of one division will be the $\frac{1}{37863}$ part of an inch: But if the screw be alter'd $\frac{1}{4}$ of one of these divisions, when the contact between the screw and feeler is well adjusted, the difference of contact (if I may so call it) will be very perceivable to the slightest observer; and, consequently, $\frac{1}{37863}$ part of an inch is perceivable in this instrument.

There is one thing still remains to be spoke of, and that is, the verification of the micrometer-screw, which is the only part of this instrument that requires exactness in the execution; and how difficult these are to make, perfectly good, is well known to every person of experience in these matters; that is, that the threads of the screw may not only be equidistant, in different places, but that the threads shall be equally inclin'd to the axis in every part of the circumference.

As nearly the same part of the screw is made use of in these experiments, the latter circumstance is what principally needs enquiry. For this purpose, let a thin slip of steel, or other metal, be prepar'd, whose thickness is about $\frac{1}{8}$ of the distance of the threads: Let the edges of this thin plate be cut into such a shape, as exactly to fit into the fix'd notch in which one end of the bar is laid: Let a screw pass thro' the standard of brass, on which that notch is

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supported, in such a manner, that the end of the bar to be measur'd that is farthest from the lever, may take its bearing against the point (or rather the small hemispherical end) of this screw: Let one of the brass bars, us'd in the other experiments, be apply'd to the instrument, and a measure taken; then let the thin plate be put in between the end of the bar and the point of the screw last mention'd, and again take the measure; but first observe, that the plate is put down to the notch, so that the same place of the plate may always agree with the point of the screw, and, consequently, no error may arise from a different thickness in different places of the plate: Observe also, that the whole comes to a true bearing; then advance the same screw till the micrometer-screw is push'd backward $\frac{1}{4}$ of a revolution; again repeat the measure with and without the thin plate; again advance the former screw, so as to make that of the micrometer recede another quarter of a turn, and repeat the measures with and without the thin plate. This method being pursu'd as far as necessary, it is evident, that, the thickness of the plate being always the same, if the difference of measures, taken with and without it, are not always the same in the different parts of a revolution of the micrometer-screw, that this screw is not equiangular; but from the differences of the measures corresponding to the thickness of the same plate, in the different parts of a revolution, the errors thereof may be nearly assign'd. For greater certainty in this examination, lest the heat of the observer's body should affect the bar or instrument during the observation, let the whole be immerg'd in the cistern of water, which ought to stand a sufficient time before

fore the observation is begun, to acquire the same temper as the air, which also ought to be in a settled state.

In this manner I examin'd such threads of this screw as were made use of in the following experiments, but did not find any material errors.

The result of the experiments made with this instrument agrees very well with the proportions of expansion of several metals given by Mr. Ellicott; which were deduced from his pyrometer publish'd in the *Philosophical Transactions*: And, considering the very different construction of the two instruments, they abundantly tend to confirm each other.

References to the Figures.

Fig. 1. represents the instrument independent of the cistern in which it is us'd.

ABCD, is the main bar or basis of the instrument.

EF, is the bar to be measur'd, lying in two notches; one fix'd to the upright standard *AB*, the other to the principal lever *HI*. The end *E* of the bar *EF*, bears against the point of

G, a screw of use in examining the micrometer-screw.

The other end of the bar *F* bears against a small spherically protuberant bit of hard metal fix'd at the same height as *G*, in the principal lever *HI*.

K, is an arbor fix'd in the basis, which receives at each end the points of the screws *HL*, upon which the lever *HL* turns, and serve as a fulcrum thereto.

O, is a slender spring, to keep the lever in a bearing state against the bar; and

P, is a check, to prevent the lever from falling forward when the bar is taken out.

N, is the feeler, something in the shape of a T, suspended, and moveable up and down upon the points of the screws *IM*, which, as well as *LH*, are so adjusted, as to leave the motion free, but without shake.

Q *R*, is the handle of the feeler, moveable upon a loose joint at *R*; so that, laying hold of it at *Q*, the feeler is mov'd up and down without being affected by the irregular pressure of the hand.

The extremity *s* of the feeler is also furnish'd with a bit of protuberant hard metal, to render its contact with the point of the micrometer-screw more perfect.

I, is the micrometer-screw; *V*, is the divided index-plate, and *W*, a knob for the handle.

The micrometer-screw passes thro' two solid screw'd holes at *D* and *F*.

The piece *YZ* is made a little springy, and endeavours to pull the screw backwards from the hole at *D*; of consequence keeps the micrometer-screw constantly bearing against its threads the same way, and thereby renders the motion thereof perfectly steady and gentle.

X, is the index, having divisions upon it, answering to the turns of the screw. This piece points out the divisions of the plate, as the face of the plate points out the divisors upon the index.

When the instrument is us'd, lay hold of the knob at *Q* with one hand, and, moving the feeler up and down, with the other move forward the screw *I*, till its

its point comes in contact with the feeler ; then will the plate and index *V* and *X* shew the turns, and parts.

Fig. 2. represents the instrument immerg'd in its cistern of water, ready for use.

AB, is the cistern; *C*, the cover; which, when the instrument *fig. 1.* is rais'd upon blocks, goes on between the bar *EF* and the basis *BC*.

D, a handle to take off the cover, when hot; *E*, the mercurial thermometer; *F*, the cock to let out the water.

GH, a hollow piece of tin, which supports seven spirit lamps, which are rais'd higher or lower by the screws *I* and *K*, in order to give the water in the cistern a proper degree of heat.

A TABLE of EXPERIMENTS,

By which the numbers in Tab. I. Col. 6. N^o 1, 2, and 4, were determin'd.

Experiment 1. The time elaps'd between approaching the bar to the instrument and taking the first measure, was half a minute: Therefore the intervals between taking the succeeding measures was half a minute also. The first measure was 208; the second $214\frac{1}{2}$; the third $216\frac{1}{2}$; the fourth $217\frac{1}{2}$. The differences of these are $6\frac{1}{2}$, 2, and 1; which pretty well tallies with the three last terms of the following geometrical progression whose common divisor is 2.8; *viz.* $17.7 : 6.3 :: 2.25 : .8$; therefore as the measures increas'd from the first, the first measure being diminish'd by the first term, *viz.* $208 - 17.7 = 190.3$,
will

will be the true measure of the bar at the first instant of its application, before it was expanded by the heat and moisture about the instrument.

Exp. 2. The first measure was $221\frac{1}{4}$; the second, 227; third, $230\frac{1}{2}$; fourth, $232\frac{3}{4}$; whose differences are $5\frac{1}{4}$, $3\frac{1}{2}$, and $2\frac{1}{4}$; agreeing with the three last terms of the following progression, whose common divisor is 1.6; viz. $9.2 : 5.8 :: 3.6 : 2.2$; therefore $221.25 - 9.2 = 212.15$.

Exp. 3. The first measure taken was 401; and at that degree of heat the wooden bar did not sensibly alter during two minutes.

Exp. 4. The first measure taken was $275\frac{1}{2}$; second, $278\frac{1}{2}$; third, $280\frac{1}{4}$; and the fourth, $282\frac{1}{4}$: The differences are, 3, $2\frac{1}{4}$, $1\frac{1}{2}$; agreeing with the three last terms of the following progression, whose common divisor is 1.43; viz. $4.4 : 3.1 :: 2.15 : 1.5$; therefore $275.5 - 4.4 = 271.1$, which is the first measure corrected.

Hence, as appears by *Tab. I.* N^o 1, 2, 3, and 4, Column 9. these experiments being properly reduc'd, agree within one division of the micrometer; and the expansion of the basis, at a medium, is $287\frac{1}{2}$ parts thereof; corresponding to 166° of Farenheit's thermometer.

TABLE

TABLE II.

A TABLE of Expansions of Metals,

Shewing, how much a foot in length of each, grows longer by an increase of heat corresponding to 180 degrees of Farenheit's thermometer, or to the difference between freezing and boiling water, express'd in such parts whereof the unit is equal to the 10000th part of an inch.

1	White glass barometer-tube.	100
2	Martial regulus of antimony.	130
3	Blister'd steel.	138
4	Hard steel.	147
5	Iron.	151
6	Bismuth.	167
7	Copper hammer'd.	204
8	Copper 8 parts, mix'd with tin 1.	218
9	Cast brass.	225
10	Brass 16 parts, with tin 1.	229
11	Brass wire.	232
12	Speculum metal.	232
13	Spelter folder, viz. brass 2 parts, zink 1.	247
14	Fine pewter.	274
15	Grain tin.	298
16	Soft folder, viz. lead 2, tin 1.	301
17	Zink 8 parts, with tin 1, a little hammer'd.	323
18	Lead.	344
19	Zink or spelter.	353
20	Zink hammer'd half an inch per foot.	373

P. S.

P. S. It is now several years since I first observ'd the very considerable expansion of the semi-metallic substance call'd *zink*, *spelter*, or *toot-anag*; and propos'd it as more fit for the purpose of making compound pendulums, and metalline thermometers, than brass; as its expansion seem'd considerably greater, and its consistence, when gently hammer'd, not much inferior. With the same view I have made trial of several other metallic compositions, besides what is above set down; but they all prov'd much inferior to *zink* in expansion, and most of them in consistence.

It seems, that metals observe a quite different proportion of expansion in a fluid, to what they do in a solid state: For regulus of *antimony* seem'd to shrink in fixing, after being melted, considerably more than *zink*.

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TAB. I. A TABLE of Experiments.

Matter of the Bars.					Cold Measure.		Middle Measure.	
N ^o					Parts of Micro-meter.	Deg. by Ther. mom.	Parts of Micro-meter.	Deg. of Ther. mom.
1	Standard bar of white deal	—	—	—	486.3	40 $\frac{1}{2}$	—	—
2	—	—	—	repeated	495.8	47 $\frac{1}{2}$	—	—
3	—	—	—	repeated	514.6	43 $\frac{1}{2}$	401.0	109
4	—	—	—	repeated	573.1	37	—	—
5	White glafs barometer tube	—	—	—	625.0	39 $\frac{1}{2}$	569.0	96 $\frac{1}{2}$
6	—	—	—	repeated	566.6	39	—	—
7	—	—	—	repeated	557.1	47	494.7	112
8	Martial regulus of antimony	—	—	—	684.1	47	—	—
9	—	—	—	repeated	751.0	39 $\frac{1}{2}$	708.0	95 $\frac{1}{2}$
10	Blister'd steel	—	—	—	685.7	40	—	—
11	—	—	—	repeated	683.8	47	638.0	113 $\frac{1}{2}$
12	Another bar from the same gad	—	—	—	719.7	40	—	—
13	Another bar from a different gad	—	—	—	740.1	40 $\frac{1}{2}$	—	—
14	—	—	—	repeated	739.9	47	694.0	114
15	Steel harden'd	—	—	—	904.5	37 $\frac{3}{4}$	855.5	113 $\frac{1}{2}$
16	Dantzick iron	—	—	—	697.5	40 $\frac{1}{2}$	—	—
17	Another bar from the same gad	—	—	—	705.8	40 $\frac{1}{2}$	—	—
18	Another bar from a different gad	—	—	—	683.9	40 $\frac{1}{2}$	—	—
19	—	—	—	repeated	683.5	47	642.9	114
20	Thick wire of English iron	—	—	—	756.0	40	—	—
21	Another rod from the same piece	—	—	—	694.9	40	—	—
22	Bismuth, or tin-glafs	—	—	—	689.6	39	—	—
23	Copper plate hammer'd	—	—	—	542.1	40	—	—
24	—	—	—	repeated	605.0	39 $\frac{1}{2}$	593.5	94 $\frac{3}{4}$
25	Another bar from the same piece	—	—	—	660.0	39 $\frac{1}{2}$	—	—
26	—	—	—	repeated	717.0	39 $\frac{3}{4}$	705.0	93 $\frac{1}{2}$
27	Copper 8 parts, with tin 1	—	—	—	721.0	47	715.0	111 $\frac{1}{2}$
28	Cast brafs hammer'd	—	—	—	581.1	39 $\frac{1}{2}$	—	—
29	—	—	—	repeated	584.2	47	582.0	112 $\frac{1}{2}$
30	The same brafs unhammer'd	—	—	—	682.4	39 $\frac{1}{2}$	—	—
31	Thick brafs wire hard drawn	—	—	—	691.2	39 $\frac{1}{2}$	—	—
32	—	—	—	repeated	694.5	47	695.5	112 $\frac{1}{2}$
33	Brafs wire softer drawn	—	—	—	741.1	39 $\frac{1}{2}$	—	—
34	Speculum metal	—	—	—	827.7	47	828.8	112
35	Brafs 16 parts, with tin 1	—	—	—	603.7	47	602.5	111 $\frac{1}{2}$
36	Speltre folder, viz. brafs 2, zink 1	—	—	—	615.0	47	624.2	111 $\frac{1}{2}$
37	Fine pewter	—	—	—	743.3	47	764.0	109 $\frac{1}{2}$
38	Grain tin	—	—	—	742.4	47	767.1	115
39	—	—	—	repeated	735.5	39	—	—
40	Soft folder, viz. lead 2, tin 1	—	—	—	681.7	47	713.0	114
41	Zink, 8 parts, tin 1, lightly hammer'd	—	—	—	753.5	38 $\frac{3}{4}$	797.5	105
42	Hard lead	—	—	—	569.5	39	—	—
43	—	—	—	repeated	617.7	47	664.5	110
44	Soft lead	—	—	—	552.7	47	609.3	110
45	Zink, or speltre	—	—	—	654.9	39	—	—
46	—	—	—	repeated	665.6	47	723.5	114 $\frac{1}{2}$
47	Zink hammer'd out half an inch a foot	—	—	—	628.0	38 $\frac{3}{4}$	693.0	106 $\frac{1}{2}$

Place this b

Middle Measure.		Hot Measure.		Extremes.			Cold and Medium.			Mean	Irre-
Parts of Micro-	Deg. of Ther-mom.	Parts of Micro-meter.	Deg. of Ther-mom.	Different Parts.	Diff. Ther-mom.	Diff. Pts re-luced to 166°.	Differ-ent Parts.	Diff. Ther-momet.	Diff. Pts re-luced to 66°.	Pts de-duced from Ex-tremes.	gula-rity.
—	—	190.3	211 $\frac{1}{2}$	—296.0	171	287.0	—	—	—	—	—
—	—	212.1	211	—283.7	163 $\frac{1}{2}$	288.0	—	—	—	—	—
01.0	109	—	—	—	—	287.0	113.6	65 $\frac{1}{2}$	114.5	—	—
—	—	271.1	211 $\frac{1}{2}$	—302.0	174 $\frac{1}{2}$	288.0	—	—	—	—	—
69.0	96 $\frac{1}{2}$	500.5	163	—124.5	123 $\frac{1}{2}$	167.5	56.0	57	65.0	66.5	+1 $\frac{1}{2}$
—	—	406.3	206	—160.3	167	159.5	—	—	—	—	—
94.7	112	398.0	208	—159.1	161	163.5	62.4	65	63.3	65.0	+1 $\frac{1}{2}$
—	—	560.0	210	—124.1	163	126.1	—	—	—	—	—
08.0	95 $\frac{1}{2}$	662.5	154	—88.5	114 $\frac{1}{2}$	128.0	43.0	56	50.7	51.0	+ $\frac{1}{4}$
—	—	564.9	210	—120.8	170	118.2	—	—	—	—	—
38.0	113 $\frac{1}{2}$	566.3	210 $\frac{1}{2}$	—117.5	163 $\frac{1}{2}$	119.0	45.8	66 $\frac{1}{2}$	45.5	47.4	+2
—	—	599.5	210	—120.2	170	117.5	—	—	—	—	—
—	—	622.3	210 $\frac{1}{2}$	—117.8	170	115.5	—	—	—	—	—
94.0	114	625.0	209	—114.9	162	117.5	45.9	67	45.1	46.7	+1 $\frac{1}{2}$
55.5	113 $\frac{1}{2}$	795.2	210	—109.3	172 $\frac{1}{4}$	105.3	49.0	75 $\frac{3}{4}$	42.7	41.9	—1
—	—	593.5	211 $\frac{1}{2}$	—104.0	171	101.0	—	—	—	—	—
—	—	604.5	210 $\frac{1}{2}$	—101.3	170	99.0	—	—	—	—	—
—	—	580.3	210 $\frac{1}{2}$	—103.6	170	101.0	—	—	—	—	—
42.9	114	583.1	209	—100.4	162	102.5	40.6	67	40.0	40.8	+ $\frac{3}{4}$
—	—	653.6	209	—102.4	169	101.0	—	—	—	—	—
—	—	593.6	207	—101.3	167	101.0	—	—	—	—	—
—	—	606.0	211	—83.6	172	80.7	—	—	—	—	—
93.5	94 $\frac{3}{4}$	511.1	205	—31.0	165	31.2	—	—	—	—	—
—	—	582.0	142	—23.0	102 $\frac{1}{2}$	37.2	11.5	55 $\frac{1}{4}$	13.7	14.8	+1
05.0	93 $\frac{1}{2}$	627.1	203	—32.9	163 $\frac{1}{2}$	33.4	—	—	—	—	—
15.0	111 $\frac{1}{2}$	694.5	139 $\frac{3}{4}$	—22.5	100	37.3	12.0	53 $\frac{3}{4}$	14.7	14.8	+1 $\frac{1}{16}$
—	—	703.7	209	—17.3	162	17.7	6.0	64 $\frac{1}{2}$	6.1	7.0	+1
82.0	112 $\frac{1}{2}$	571.8	210	—9.3	170 $\frac{1}{2}$	9.1	—	—	—	—	—
—	—	575.0	208 $\frac{1}{2}$	—9.2	161 $\frac{1}{2}$	9.5	2.2	65 $\frac{1}{2}$	2.2	3.8	+1 $\frac{1}{2}$
—	—	673.5	210	—8.9	170 $\frac{1}{2}$	8.7	—	—	—	—	—
—	—	691.0	210	—0.2	170 $\frac{1}{2}$	0.2	—	—	—	—	—
95.5	112 $\frac{1}{2}$	692.3	209 $\frac{1}{2}$	—2.2	162 $\frac{1}{2}$	2.2	1.0	65 $\frac{1}{2}$	1.0	0.9	—1 $\frac{1}{10}$
—	—	741.1	210	—0.0	170 $\frac{1}{2}$	0.0	—	—	—	—	—
28.8	112	826.5	208 $\frac{1}{2}$	—1.2	161 $\frac{1}{2}$	1.2	1.1	65	1.1	0.5	— $\frac{1}{2}$
02.5	111 $\frac{1}{2}$	597.6	209	—6.1	162	6.3	1.2	64 $\frac{1}{2}$	1.2	2.5	+1 $\frac{1}{4}$
24.2	111 $\frac{1}{2}$	632.5	209	+17.5	162	17.9	9.2	64 $\frac{1}{2}$	9.4	7.1	—2 $\frac{1}{4}$
64.0	109 $\frac{1}{2}$	793.8	211	+50.5	164	51.1	20.7	62 $\frac{1}{2}$	21.8	20.4	—1 $\frac{1}{2}$
67.1	115	818.2	209	+75.8	162	76.8	24.7	68	24.0	30.5	+6 $\frac{1}{2}$
—	—	822.6	210	+87.1	171	84.5	—	—	—	—	—
13.0	114	765.0	210	+83.3	163	84.7	31.3	67	30.8	33.7	+3
97.5	105	826.5	147	+73.0	108 $\frac{1}{4}$	111.8	44.0	66 $\frac{1}{4}$	43.9	44.4	+ $\frac{1}{2}$
—	—	721.7	211	+152.2	172	147.2	—	—	—	—	—
64.5	110	753.0	211	+135.3	164	136.5	46.8	63	49.0	54.3	+5 $\frac{1}{4}$
09.3	110	680.7	211	+128.0	164	129.5	56.6	63	59.2	51.5	—7 $\frac{1}{4}$
—	—	810.0	211 $\frac{1}{2}$	+155.1	172 $\frac{1}{2}$	149.0	—	—	—	—	—
23.5	114 $\frac{1}{2}$	812.0	210	+146.4	163	149.0	57.9	67 $\frac{1}{2}$	56.5	59.4	+3
93.0	106 $\frac{1}{2}$	744.5	150	+116.5	111 $\frac{3}{4}$	173.0	65.0	68 $\frac{1}{4}$	63.0	68.9	+6

Place this between p. 610, 611.

Fig. 1. p. 608.

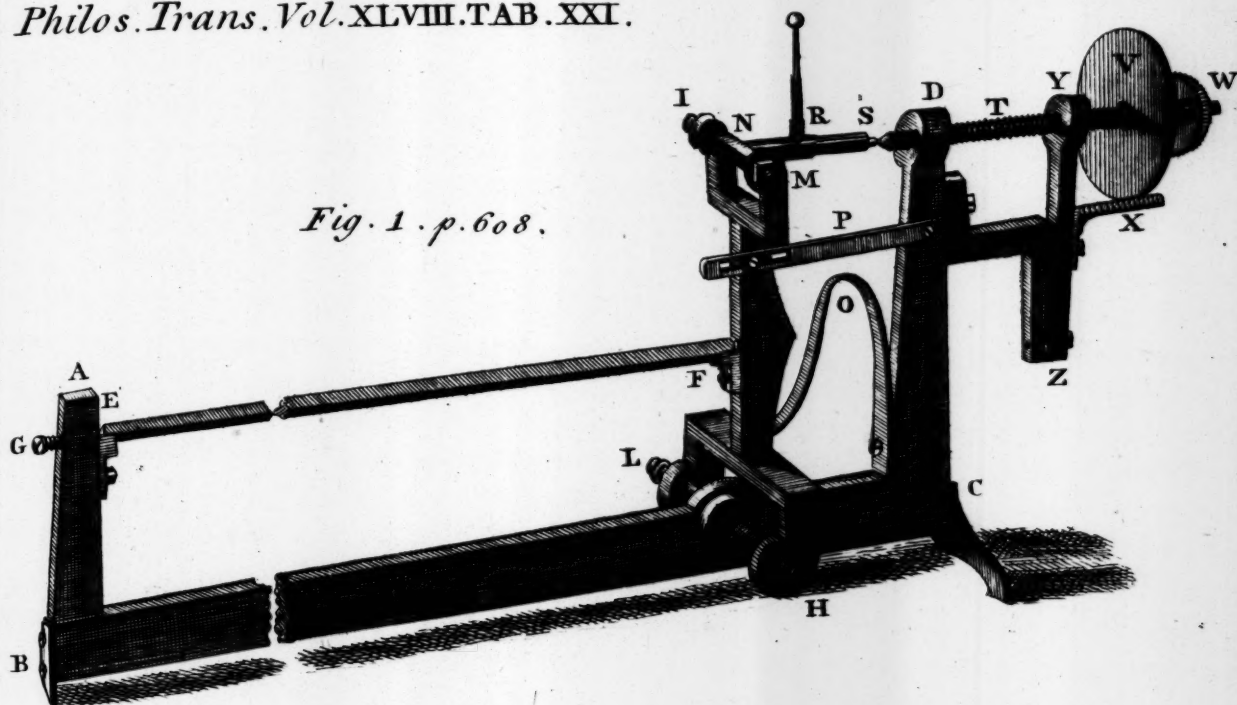


Fig. 2. p. 609.

